

ON ESTIMATION OF ENVIRONMENTAL
INDUSTRIAL NOISE

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ABSTRACT

Measuring equipment with a built in true integrator is today fairly common. This means that it is convenient to measure the equivalent sound pressure, L_{eq} , e.g. for outdoor industrial noise. Often the industry in view considered as sound source can be modelled into one or more stationary random processes, each called a state. L_{eq} is measured for each state and regarded as an estimate of the true mean value. The report discusses the quality of the estimates taking into account the properties of the source and the channel process.

A measurement strategy is outlined which has a more well-founded structure than the method given in "LAY-OUT FOR ISO/DIS 1996/1". The aim is to obtain good estimates of L_{eq} and the measurement strategy, proposed in this paper makes this possible. Mathematical models of the source and the channel are used and a basis is given such that confidence intervals can be estimated and the total measurement time effectively used.

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1. INTRODUCTION

A. Background and outline

External noise from industries is often spread over residential areas. In many countries codes are used to prevent noise levels from being too high. In some cases the permitted levels are fairly low which means that measurements are required also at great distances.

The noise from industries fluctuates partly because each individual sound source gives varying sound power and partly because of the complex on/off pattern for these sources. The attenuation of the sound path, i.e. the channel, also varies strongly in the long term because of weather, wind direction and wind velocity and in the short term because of turbulence.

The situation for estimating industrial noise thus seems rather chaotic. Different types of measurement are used to deal with the varying sound levels and with the long term effects on man. It is very common to use the energy equivalent sound pressure level, L_{eq} , in dBA in connection with the latter effects.

The equivalent sound pressure level for the time interval $0 \leq t \leq T$ is defined by

$$L_{eq} = 10 \log (\bar{p}_T / p_{ref}^2) \quad (1.1)$$

where

$$\bar{p}_T = \frac{1}{T} \int_0^T p^2(t) dt, \quad (1.2)$$

$$p_{ref} = 20 \cdot 10^{-6} \text{ Pa} \quad (1.3)$$

and $p(t)$ the instantaneous sound pressure. If a representative value is to be achieved from measurements, without knowing anything in advance about the source and the channel, the time interval for the measurements must be very long.

A way to deal with this is to model the industry as a stationary random sound source. As there are on/off situations it also seems convenient to develop this model further to comprise a few different stationary processes modelling the different on/off situations, called states. This is sensible if the on/off pattern varies slowly compared to the variations within the individual states. The channel should also be classified in states to straighten the measuring situation.

B. Inner and outer process and modulation

The assumed stationary industrial noise is handled in the following way. Some of the variables involved in the process are used as parameters and kept constant in a certain combination. This defines the inner process connected with one special state of the industry and state of the channel (weather and wind).

The fluctuations connected with shifting of states, i.e. the on/off pattern, can also be viewed as modulation of the sound power as this change is normally a slow process compared to the inner processes.

The modulation can thus be considered as an outer random process that acts on the inner ones and gives the total process. The modulation may also be handled in a deterministic way. This will often give a more handy situation and thus promote the strategy given in this paper.

C. Details of the measurement strategy

The so far outlined measurement strategy implies that the aim is to estimate the mean value

$$m_i = E \{p_i^2(t)\} \quad (1.4)$$

for every inner process or state, i , individually. The notation $E\{ \}$ means statistical expectation. Then we look upon the modulation as an outer stationary process and calculate the total expected value, m , from the mean values, m_i , of the inner processes and the probabilities of occurrence, S_i of the states, by

$$m = \sum_{i=1}^N S_i m_i \quad (1.5)$$

where

$$\sum_{i=1}^N S_i = 1 \quad (1.6)$$

and N the number of states. Expressing this in levels we have

$$L_{eqi} = 10 \log \frac{m_i}{p_{ref}^2} \quad (1.7)$$

and

$$L_{eq} = 10 \sum_{i=1}^N S_i 10^{L_{eqi}/10} \quad (1.8)$$

This means that L_{eq} is redefined.

D. Variance versus measurement strategy

The received signal power integrated over 1 s, i.e. sound level SLOW, has in general a fairly large variance. The increased measuring time when using L_{eq} will give a decreased variance on a certain condition connected to the covariance function of $p^2(t)$ denoted by $c(\tau)$. The normalized covariance

$$\rho(\tau) = \frac{c(\tau)}{c(0)} \quad (1.9)$$

is in general small for τ greater than a certain value τ_0 . The decrease of the variance is negligible if the measuring time is less than τ_0 . For greater measuring time the variance decreases with τ_0/T where T is the estimation time. We note that if τ_0 is limited the variance can be decreased.

The total process often has a very large τ_0 because of slow on/off modulations of the states. Dividing the measurements to be performed into different inner processes, states, is a way of obtaining much shorter τ_0 -values. The gain of this is often so great that it more than compensates for the time consumed on the estimation of the different inner processes.

2. MATHEMATICAL MODELS OF INDUSTRIAL NOISE

A. The Source

Industrial noise fluctuates in general. However there are industries which have an almost constant noise level e.g. chemical processing industries. In this latter case it is natural to model the noise by one stationary random process. For more fluctuating noise we have to consider introducing a number of stationary random processes as outlined in chapter 1. This means that we describe the industrial noise by a number of states. How many states one should introduce depends on the correlation characteristics of the noise. In fact we also have to consider the fluctuation of the channel when we choose the states. However here we leave this complication for a while and return to it after having treated the channel fluctuations.

The main rule is to use as few states as possible and states that are easy to define and detect.

The reason why one had to use a number of states was to get a good estimate and an effectively used total estimation time. Let us illustrate this in an example. We describe the noise intensity, $I(t)$, by

$$I(t) = \frac{p^2(t)}{\rho c} = y^2(t) (1 + mx(t)) \quad (2.1)$$

Where ρc is acoustic impedance, $p(t)$ the sound pressure and m a constant such that

$$|m| < 1 \quad (2.2)$$

The signal $y(t)$ is stationary zero-mean Gaussian noise and $x(t)$ is an on-off process. The processes are statistically independent. The process $x(t)$ is generated by a Markov process with two states, $+1$ and -1 . The probability of being in state $+1$ is a priori known to be α . The mean time in state $+1$ denoted by T_+ is given by

$$E \{T_+\} = \frac{T}{\beta} \quad (2.3)$$

and the mean time in state -1 is

$$E \{T_{-1}\} = \frac{T}{\alpha} \quad (2.4)$$

where

$$\alpha + \beta = 1 \quad (2.5)$$

The mean value of $x(t)$ is

$$\mu_x = E\{x(t)\} = +1\alpha - 1\beta = \alpha - \beta \quad (2.6)$$

and

$$r_x(\tau) = E\{x(t) x(t + \tau)\} = (\alpha - \beta)^2 + 4\alpha\beta e^{-\tau/T} \quad (2.7)$$

This means that the covariance function is

$$c_x(\tau) = 4\alpha\beta e^{-\tau/T} \quad (2.8)$$

We now return to $I(t)$ and find

$$\mu_I = E\{I(t)\} = r_y(0) (1 + m\mu_x) = \sigma_y^2 (1 + m(\alpha - \beta)) \quad (2.9)$$

where $r_y(\tau)$ is the correlation function of $y(t)$ and $\sigma_y^2 = r_y(0)$. We find

$$r_I(\tau) = E\{I(t) I(t + \tau)\} =$$

$$= (2 r_Y^2(\tau) + r_Y^2(0)) (1 + 2m\mu_X + m^2 r_X(\tau)) \quad (2.10)$$

and the covariance function

$$c_I(\tau) = r_I(\tau) - \mu_I^2 =$$

$$2c_Y^2(\tau) \left(1 + 2m\mu_X + m^2 (\mu_X^2 + c_X(\tau)) \right) + \sigma_X^4 m^2 c_X(\tau) \quad (2.11)$$

We now assume, for increasing τ -values, that $c_Y(\tau)$ converges towards zero much faster than $c_X(\tau)$. This means that for large τ we have

$$c_I(\tau) \simeq \sigma_Y^4 m^2 c_X(\tau) \quad (2.12)$$

We now observe that if we make a one state approach of $I(t)$ and estimate μ_I by

$$\hat{\mu}_I = \frac{1}{T} \int_0^T I(t) dt, \quad (2.13)$$

the variance of this estimate will then equal

$$V\{\hat{\mu}_I\} = \frac{2}{T} \int_0^T \left(1 - \frac{\tau}{T} \right) c_I(\tau) d\tau \quad (2.14)$$

This means that for large τ it is $c_X(\tau)$ that rules the variance and then τ_0 , defined in chapter 1, becomes large. In order to obtain a small variance one therefore has to use a long estimation time T .

Let us now divide $I(t)$ into two states and estimate the mean value of

$$I(t | x(t) = +1) = y^2(t) (1 + m) \quad (2.15)$$

and

$$I(t | x(t) = -1) = y^2(t) (1 - m) \quad (2.16)$$

separately. This means that the estimates

$$\hat{\mu}_{I+} = \frac{1}{T_1} \int_0^{T_1} I(t | x(t) = +1) dt \quad (2.17)$$

and

$$\hat{\mu}_{I-} = \frac{1}{T_2} \int_{T_3}^{T_3 + T_2} I(t | x(t) = -1) dt \quad (2.18)$$

will have a variance equal to

$$V\{\hat{\mu}_{I+}\} = 4(1 + m)^2 T_1 \int_0^{T_1} \left(1 - \frac{\tau}{T_1}\right) c_Y^2(\tau) d\tau \quad (2.19)$$

and

$$V\{\hat{\mu}_{I-}\} = 4(1 - m)^2 \frac{1}{T_2} \int_0^{T_2} \left(1 - \frac{\tau}{T_2}\right) c_Y^2(\tau) d\tau \quad (2.20)$$

respectively. We note that, since $c_Y(\tau)$ converges towards zero much faster than $c_X(\tau)$, the estimation time may here be chosen much shorter than for the one state approach. The estimate of total mean value of $I(t)$ is for this two-state approach given by

$$\hat{\mu}_{I_2} = \hat{\mu}_{I+} \alpha + \hat{\mu}_{I-} \beta \quad (2.21)$$

This estimate is unbiased. We also assume that $\hat{\mu}_{I+}$ and $\hat{\mu}_{I-}$ are independent and then the variance of $\hat{\mu}_{I_2}$ becomes

$$V(\hat{\mu}_{I_2}) = \alpha^2 V\{\hat{\mu}_{I+}\} + \beta^2 V\{\hat{\mu}_{I-}\} \quad (2.22)$$

One may now go further with this analysis and introduce more states. We will however be content with this two-state analysis and note that the motive of introducing states must be to improve the estimate and effectively use the total estimation time. In the example above the theoretical basis of this is given.

B. The Channel

In a research project conducted by Nordforsk the attenuation of the channel has been studied. It has been found e.g. in [1] and [2], that it is mainly the wind direction, the wind velocity and the temperature gradient that affect the attenuation of the channel. Since these meteorological parameters fluctuate we get an attenuation which fluctuates.

In Fig. 2.1, taken from [1], the spectra of these meteorological parameters are shown.

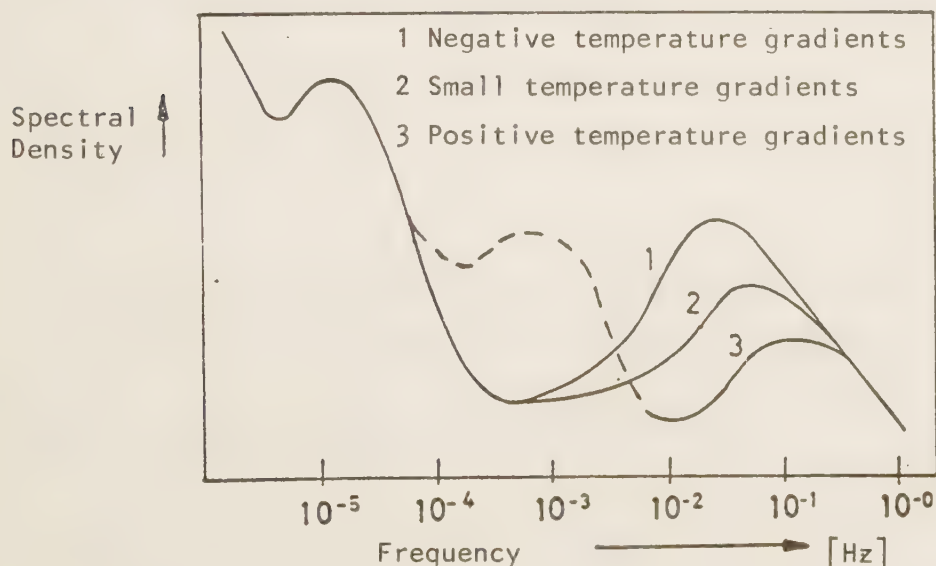


Figure 2.1 Schematic diagram of the spectral density of the meteorological parameters, which are important to the sound propagation.

The characteristic features of Fig. 2.1 are the two maxima which mean slow and fast fluctuations respectively. The right maxima has the centerfrequency $(1 \text{ minute})^{-1}$. This means that if we choose an estimation time of, for example, 10 minutes we get an average over these relatively rapid fluctuations. If the meteorological parameters are not at all restricted during the estimation time one may find an attenuation which fluctuates about 20 - 30 dB. Therefore one has to specify a certain meteo-window that describes the permitted weather conditions during the estimation time. The meteo-window will in Sweden be something close to:

- downwind within $\pm 45^\circ$
- wind velocity: 2 - 5 m/s at 10 m above the ground
- low temperature gradient, less than 0.05° C/m

By using this meteowindow and [1] one can find a standard deviation, σ_s , caused by slow meteorological fluctuations. We here adopt the proposition that σ_s is given by

1.2 dB	for a distance of	100 m	and
2.0 dB	" " "	200 m	and
2.5 dB	" " "	"	

The standard deviation, σ_f , of the fast fluctuations is for an estimation time of 10 minutes adopted to be

0.75 dB	for a distance of	100 m	and
1.5 dB	" " "	200 m	and
2.25 dB	" " "	400 m	

We now assume that the corresponding sound levels, the slow and the fast, are independent and additive in dB. Then the standard deviation for one estimation made over 10 minutes is given by

$$\sigma_m = \sqrt{\sigma_s^2 + \sigma_f^2} \quad (2.23)$$

This means that the standard deviation, σ_m , caused by weather fluctuation within the meteo-window is approximately

1.4 dB at a distance of 100 m and

2.5 dB " " " " 200 m and

3.4 dB " " " " 400 m .

The estimated values of the standard deviation are calculated pessimistically for 1/1-octave bands from 63 Hz to 8 kHz. This means that for broadband measurements, for example A-weighted measurements, one may expect a lower value of the standard deviation. However in many situations the source has a small bandwidth. Therefore we keep using these standard deviations for both broadband and for 1/1-octave band measurements.

If one makes an N number of independent measurements, in practice measurements on N number of different days, the expected value of the standard deviation of the mean value is given by

$$\sigma_{m,N} = \frac{\sigma_m}{\sqrt{N}} \quad (2.24)$$

where σ_m is the standard deviation for one measurement at a given distance.

The strategy of making measurements is chosen to be in accordance with this. That means independent measurements all made with the estimation time 10 minutes. We assume measurements made on different days to be independent.

C. The source once again

We announced in section A of this chapter that one also has to consider the channel fluctuation when choosing the states. In section B it was found that a suitable integration time to be used is 10 minutes. This means that dividing the source into additional states that require an integration time essentially less than 10 minutes is pointless.

3. THE ESTIMATION PROBLEM

A. Introduction

The aim is to estimate L_{eq} defined in chapter 1 and a confidence interval for L_{eq} . How to calculate L_{eq} is shown in chapter 1. The confidence interval estimation requires knowledge of the standard deviation and the distribution. If one uses the meteo-window and a stationary source that gives negligible fluctuations it is found that the noise level in dB is almost Gaussian distributed [5]. This means that it is suitable to consider the estimate of L_{eq} made over 10 minutes as a Gaussian random variable. We therefore almost everywhere estimate the standard deviation directly in dB. This standard deviation then gives

$$\hat{\delta} = 1.3 \hat{\sigma} \quad (3.1)$$

which we name as the uncertainty and by using this we obtain an approximately 90 % confidence interval. If we have an N number of independent measurements the estimate of the equivalent level L_{eq} is given by

$$\hat{L}_{eq} = 10^{-10} \log \frac{1}{N} [10^{\hat{L}_i / 10}] \quad (3.2)$$

where $\hat{L}_i$ is the equivalent sound level from the i:th measurement. We now construct the one sided confidence interval

$$L_{eq} \leq \hat{L}_{eq} + \hat{\delta}_N \quad (3.3)$$

where

$$\hat{\delta}_N = 1.3 \hat{\sigma}_N \quad (3.4)$$

and $\hat{\sigma}_N$ the estimated standard deviation in dB for $\bar{L}$ defined by

$$\bar{L} = \frac{1}{N} \sum_{i=1}^N L_i \quad (3.5)$$

Since

$$\hat{L}_{eq} \geq \hat{\bar{L}} = \frac{1}{N} \sum_{i=1}^N \hat{L}_i \quad (3.6)$$

we obtain a confidence level slightly higher than 90 %.

We shall now prove (3.6). It is well known that

$$\sqrt[N]{\prod_{i=1}^N \frac{L_i}{10}} \leq \frac{1}{N} \sum_{i=1}^N \frac{L_i}{10} \quad (3.7)$$

since the geometric mean value is always less than or equal to the arithmetic mean value. We take the logarithm of left and right side of (3.7) and find

$$\frac{1}{N} \sum_{i=1}^N \frac{L_i}{10} \leq \log \left[\frac{1}{N} \sum_{i=1}^N 10^{L_i/10} \right] \quad (3.8)$$

Multiplying left and right side of (3.8) by 10 gives (3.6).

Let the sound level in a point close to the source be denoted by L_S and the sound level in a distant point by L_D . The attenuation of the channel may then be defined by

$$L_A = L_S - L_D \quad (3.9)$$

If we assume that L_A and L_S are independent we find the following relation between the variances:

$$\sigma_{L_D}^2 = \sigma_{L_S}^2 + \sigma_{L_A}^2 \quad (3.10)$$

We will now try to treat the different measurement situations and find an estimate of L_{eq} and an estimate $\hat{\delta}$, the uncertainty, that give the confidence interval. This procedure is developed by the authors of this paper in co-operation with the Nordforsk group on industrial noise.

B. Measurements made on one occasion

1. Measurement made on one state

The measurement is here made during one fixed state.

a)

If we can assume that the noise from the source, the inner process, does not give a standard deviation greater than 1 dB for the estimation time 10 minutes, then the uncertainty is given in table 1.

TABLE 1

The uncertainty, $\hat{\delta}$, at one measurement, with the estimation time 10 minutes.

<u>100 m</u>	<u>200 m</u>	<u>400 m</u>
2 dB	3.5 dB	4.5 dB

These figures are rounded off results from calculations using (3.10) and

$$\hat{\delta} = 1.3 \sqrt{1 + \sigma_m^2} \quad (3.11)$$

b)

If one cannot assume that the noise from the source, the inner process, gives a standard deviation less than or

equal to 1 dB one has to make a number of independent measurements. They are performed either according to C below or through making at least three independent measurements on a short distance, if possible less than 25 meters', from the source.

The standard deviation σ_s from N measurements is estimated by

$$\begin{aligned}\sigma_s &= \sqrt{\frac{1}{N-1} \sum_{i=1}^N \left(\hat{L}_i - \frac{1}{N} \sum_{j=1}^N \hat{L}_j \right)^2} = \\ &= \sqrt{\frac{1}{N-1} \left[\sum_{i=1}^N \hat{L}_i^2 - \frac{1}{N} \left(\sum_{i=1}^N \hat{L}_i \right)^2 \right]}\end{aligned}\quad (3.12)$$

where $\hat{L}_i$ is the equivalent sound level estimate from the i:th measurement.

The total standard deviation is estimated by

$$\hat{\sigma} = \sqrt{\hat{\sigma}_s^2 + \hat{\sigma}_m^2} \quad (3.13)$$

where $\hat{\sigma}_m$ is given in chapter 2. The uncertainty $\hat{\delta}$ is now again given by

$$\hat{\delta} = 1.3 \hat{\sigma} \quad (3.14)$$

2. Measurements made on different states

The estimation of L_{eq} is here given in chapter 1. If case a) above is valid the uncertainty is estimated by $\hat{\delta}$ given in table 1. If case b) is valid the uncertainty may be estimated by the greatest individual uncertainty or through a calculation according to C below.

C. Measurements made on independent occasions

1. Measurements made on one state

Through measurements made on a number of independent occasions the accuracy can be increased i.e. the uncertainty decreased. This is due to the fact that here we will use the measurements not only to estimate L_{eq} but also to estimate the actual standard deviation. This will in general result in a notably decreased standard deviation since the standard deviation given in chapter 2 are pessimistic estimates. The standard deviation is estimated by means of (3.12) where $\hat{L}_i$ is the equivalent sound level estimate from the i :th measurement. The task is to find the uncertainty. However the uncertainty depends upon the measurement strategy. Here we treat two different strategies.

a) An in advance fixed number of measurements

If the number of measurements is in advance fixed and not dependent on, for example the results, the uncertainty is given by

$$\hat{\delta} = s \frac{t_N}{\sqrt{N}} \quad (3.15)$$

where N is the number of measurements and t_N is given in table 2. This means that we have used the Student t distribution.

TABLE 2

The factor t_N

t_N :	3.1	1.9	1.6	1.5	1.4	1.3
N :	2	3	4	5.6	7 - 15	16 -

This procedure will give approximately a 90 % confidence interval.

b) Number of measurements depending on the results

In this case the number of measurements is not fixed in advance. The strategy is the following: Start by making two independent measurements and estimate the standard deviation s_2 by (3.12), $N = 2$, and the uncertainty $\hat{\delta}_2$ given by

$$\hat{\delta}_N = s_N \frac{t'_N}{\sqrt{N}} \quad (3.16)$$

where t'_N is given in table 3.

TABLE 3

The factor t'_N

t'_N :	6.3	4.4	3.8	3.2	3.0	2.8	2.6	2.4
N :	2	3	4	5	7	10	15	20

If the received confidence interval is satisfactory, no more measurements are made. If however the result is not satisfactory, one makes one more measurement and calculates s_3 and $\hat{\delta}_3$ and finds out if the result is satisfactory and so on. Note that the number of measurements will increase from 5 to 7, from 7 to 10, from 10 to 15 and finally from 15 to 20. The strategy means that a sequential test is used. The Student t distribution may then not be used directly. However it is possible to find a lower bound of the confidence level by means of Student t distribution. One then uses level $1 - \alpha_2$ for 2 measurements, level $1 - \alpha_3$ for three measurements and so on. The confidence level of the sequential test has then a lower bound given by

$$\beta = 1 - \alpha = 1 - \alpha_2 + \alpha_3 + \alpha_4 + \dots \quad (3.17)$$

The figures $\alpha_2, \alpha_3, \dots$ may be chosen arbitrarily provided that $\alpha = \alpha_2 + \alpha_3, \dots$.

In the test suggested in this paper we have chosen $\alpha_2, \alpha_3, \dots$ such that t'_N decreases for a increasing value of N . The values of t'_N given in table 3 are chosen such that the lower bound becomes 85 %.

2. Measurements from different states

Here it is very difficult to estimate a confidence interval since we have a sum of random variables with unknown mean values and unknown standard deviations. One way is therefore not to give an estimated confidence interval. We will however suggest something that can be used.

We will here give two possibilities.

a) A rough conservative estimate

Let the uncertainty for L_{eq} be the greatest individual state uncertainty.

b) Energy equivalent estimation

Suppose that K number of states are to be weighed to form $\hat{L}_{eq}$ given by

$$\hat{L}_{eq} = 10^{-10} \log \left[\frac{1}{T_s} \sum_{k=1}^K T_k 10^{\hat{L}_k/10} \right] \quad (3.18)$$

Where $\hat{L}_k$ is the estimated equivalent sound level of the state k , T_k the working time of state k and finally T_s the total working time.

$$T_s = \sum_{k=1}^K T_k \quad (3.19)$$

The standard deviation for the state k is calculated according to

$$\begin{aligned} s_{k,e} &= \sqrt{\frac{1}{N_k - 1} \left[\sum_{i=1}^{N_k} (10^{\hat{L}_{i,k}/10})^2 - \frac{1}{N_k} \left(\sum_{j=1}^{N_k} 10^{\hat{L}_{j,k}/10} \right)^2 \right]} \\ &= \sqrt{\frac{1}{N_k - 1} \left[\sum_{i=1}^{N_k} (10^{\hat{L}_{i,k}/10})^2 - \frac{1}{N_k} \left(\sum_{i=1}^{N_k} 10^{\hat{L}_{i,k}/10} \right)^2 \right]} \end{aligned} \quad (3.20)$$

where $\hat{L}_{i,k}$ is the equivalent sound level estimate from the i :th measurement of N_k on state k .

The weighed total standard deviation is estimated by

$$s_e = \sqrt{\sum_{k=1}^K \left(\frac{T_k}{T_s} \right)^2 \frac{s_{k,e}^2}{N_k}} \quad (3.21)$$

The uncertainty depends on the measurement strategy. If the number of independent measurements is fixed in advance the uncertainty is calculated by

$$\hat{\delta}_e = s_e t_{N'} \quad (3.22)$$

Where N' is defined by

$$N' = \min_{k=1}^K (N_k) \quad (3.23)$$

and $t_{N'}$ by table 2.

If, however, the number of measurements is dependent upon the result one uses the procedure C1b above. The uncertainty is then calculated by

$$\hat{\delta}_e = s_e t'_{N'} \quad (3.24)$$

where $t'_{N'}$ is given in table 3.

The upper limit of the confidence interval is

$$10^{-10} \log (10^{\hat{L}_{eq}/10} + \delta_e) \quad [\text{dB}] \quad (3.25)$$

D. Some remarks

This procedure for estimating L_{eq} and finding the uncertainty shall be considered as a first step towards a practical and scientifically founded procedure. We have taken the step of introducing estimation of the standard deviation of $\hat{L}_{eq}$. We have also given a procedure of how to find a confidence inter-

val. This is as pointed out only a first step and there is a lot of statistical work to do before we reach the goal: a good statistical and practical model.

4. A REFERENCE SYSTEM ASSISTING ESTIMATION OF ENVIRONMENTAL INDUSTRIAL NOISE

A. Compensation of unwanted atmospheric influence

When estimating the expected value of a state it is often difficult to break for all weather and wind alterations outside the meteo-window. One way to cope with this is to transmit sound from an artificial sound source parallel to the industrial noise. Starting with a well defined measuring situation within the meteo-window, any slow fluctuation in the sound path attenuation can be corrected by means of a parallel reference sound.

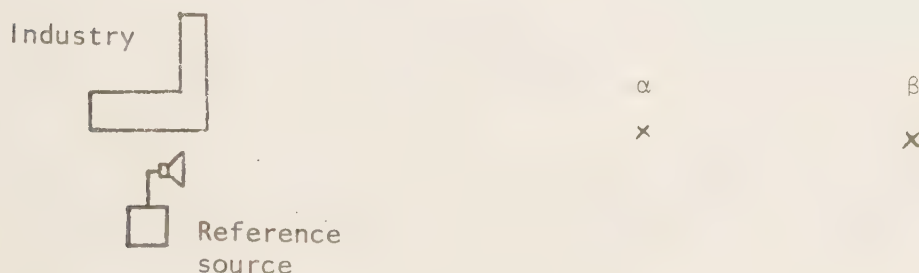
One problem with a reference path is the power demand for the source that also can be annoying if it is strong. The power can be decreased if the received signal is processed in a suitable way using correlation methods. Such methods are also used in connection with internal industrial noise. Then the correlation is usually performed directly on the signal, [4]. Outdoors this is often less efficient because of phase fluctuation from turbulence, [5]. Instead the sound power is modulated and the received power is correlated with the transmitted modulation, [6]. This gives a system that can handle the turbulence as the modulations give "wavelengths" that are large compared to the turbulence size.

B. Other applications

We may make use of a reference system provided that the sound emission of the industry and the reference source are equal or almost equal. This means that the reference source must be located closely to the acoustic centre of the industry. In some situations there does not exist an acoustical centre. Then one has to use a number of

equally modulated independent reference sources located in such a way that the sound emission equals or almost equals the sound emission of the industry. In many situations it is however sufficient to model the sound emission correctly only in a limited space angle around the measuring direction. We will not, in this paper, treat this emission problem but will be content with noting that the problem exists and assuming that it has been satisfactorily solved.

Let us consider Fig. 4.1 and assume that the industry noise can be measured in point α but not in point β because of a too low signal-to-noise ratio in this point.



We note that α and β are points situated in approximately the same direction from the industry. The reference system may then easily be used estimating the attenuation difference between the points. Then the sound level of the industry in the point β can be estimated. This is due to the fact that the reference system can handle situations with very low signal-to-noise ratios.

This quality may also be used to estimate the sound path attenuation at very long distances, [6], [7]. The grounds for this are very good especially if one uses the power modulation correlator designed in [8]. This correlator uses pauses in the correlation procedure in such a way that the transients from the modulation become cancelled.

5. CONCLUSIONS

We have in this paper studied outdoor industrial noise and the problem of estimating and finding confidence intervals for L_{eq} . It is found convenient to carry out a number of independent measurements each having a 10 minute integration time. Furthermore it is suitable to divide the source into a number of states.

The outlined strategy for measurements has shown to form a basis such that confidence intervals can be estimated and the total measuring time effectively used. We judge this method as being a first step towards a well designed statistical and practical model. Compared to the ad hoc measurement strategy, performed without any model of the source and channel, this method constitutes however an essential step forwards, clarifying the measurement situation.

Finally we have seen that a reference measuring system can be a useful tool for measurements of outdoor industrial noise.

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